Geotextiles and Loess: Long-Term Flow

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The ability of a geotextile to separate soils having varying grain size distributions while still allowing for flow makes them ideally suited for erosion control and filtration applications. A well-engineered and constructed silt fence will satisfy three design criteria: adequate permeability, soil retention, and soil compatibility. This project is focused on soil-geotextile compatibility. Several test methods exist to evaluate soil-geotextile compatibility. The Long-Term Flow (LTF) test, in which soil is placed above the candidate geotextile and a constant head of water is applied above the soil was used in this study. Water flows through the soil/geotextile for a long period to determine the compatibility condition of steady flow or non-steady flow rates of excessive clogging or soil piping. Nine geotextiles supplied for the silt fence market are being tested. Mid-Missouri loess is the candidate soil. Test results to date indicate soil-geotextile compatibility, i.e., the geotextiles do not clog excessively nor do the loess particles pass through the geotextiles. However, the flow rates are low initially and subsequently decrease, becoming steady after 2,000 hours of flow. While not clogging the geotextile per se, the subsequent decrease in flow rate may contribute to the geotextiles having an insufficient flow capacity to be effective silt fences or filters in loess. Key words: loess, silt fence, excessive clogging, piping, soil-geotextile compatibility, filtration.

INTRODUCTION

Erosion accounts for 3.3 billion metric tons of soil loss per year in the US (*1*). Fifteen percent or 500 million tons of that loss is attributed to construction sites, many of which are road, rail and other transportation sites. During construction, it is often not practical to cover all the open soil to prevent erosion, and a rainstorm can create a significant amount of sediment-laden run-off. This sediment load can flow off the property and pollute native waterways (fish habitat), clog sewers, collect on other property, and result in the loss of valuable topsoil. Erosion is particularly critical in the Missouri river system, a region known for its wind-deposited, highly erodible loess soil. Significant structural damage to infrastructure is attributed to erosion, and the United States Environmental Protection Agency's National Pollutant Discharge Elimination System (NPDES) regulations now cover non-point sources, including sediment load to surface waters (*2*).

Geotextiles offer a solution for controlling runoff and sedimentation and can significantly reduce river, lake and stream pollution from unwanted sediment. A well-designed silt fence (Figure 1) will initially screen silt and sand particles from the runoff water forming a soil filter and reducing the ability of water to flow. The initial clogging of the geotextile creates a pond of relatively still water that serves as a sedimentation basin to collect the suspended soil from the runoff water (Figure 1b). A silt fence must retain water long enough for suspended particles to settle out while still maintaining adequate permeability to prevent overtopping. Two concerns in the use of geotextile silt fences are the potential of the geotextile to excessively clog and prevent flow through the fence and for the soil to pipe or pass through the geotextile.

A geotextile that neither clogs nor pipes soil fines is considered compatible with the soil in question. Silts and other fine soil with little cohesion have been notably problematic and exhibit poor compatibility (*3*). Loess, a low or non-cohesive, highly erosive soil located throughout the Midwest falls in this "problematic" category. The objective of this study is to evaluate the long-term filtration compatibility of geotextiles with loess. Nine geotextiles, marketed for the silt fence applications are being tested for compatibility with a central Missouri loess.

METHODS AND MATERIALS

Several test methods have been established to evaluate the long-term flow compatibility of geotextile-soil systems (*3*). The Long-Term Flow (LTF) test is being used in this study, see Figure 2. In this procedure, soil is placed above the candidate geotextile and a supply of water under constant head is applied above the soil.

Flow is continuous and flow rate measurements are taken periodically. The flow rates are examined for changes over time. The resulting flow rates are plotted as shown in Figure 3.

The time-to-transition, shown in Figure 3 as t_t, is the time where the soil-geotextile system will begin its field-simulated behavior (*4*). The initial slope, m_i, is due to the densification of the soil due to the downward flowing water and is not of direct interest if only excessive clogging or piping of the geotextile are of concern (*3*). If after this time, the slope of the curve becomes steady (zero), the geotextile is considered compatible with the soil. If the final or terminal slope, m_f, becomes positive the soil is considered to be piping through the geotextile. If the slope continues to be negative, the soil is considered to be excessively clogging the geotextile. For the latter two cases, the geotextile may not be suited, i.e., able to meet its design criteria of adequate permeability and/or soil retention for this type of soil. Tests typically require about 1,000 hours of flow to establish the terminal slope shown in Figure 3.

Test Setup and Procedure

A diagram of the apparatus used in this study is shown in Figure 2. Six test cylinders were designed and built in order to test a series of geotextiles simultaneously. The flanged test cylinders were constructed from two cylindrical pieces of clear plastic. Each test cylinder has an inside diameter of 100 mm (4 in). The candidate geotextile, wire mesh support screen and rubber O-ring are placed in the seat of the lower cylinder (Figure 2,A-A). A thin film of vacuum grease is applied to the flange of the lower cylinder to prevent leaks and bolted to the upper cylinder. A constant hydraulic head is maintained through the fixed inlet and outlet ports of the upper cylinder. The system

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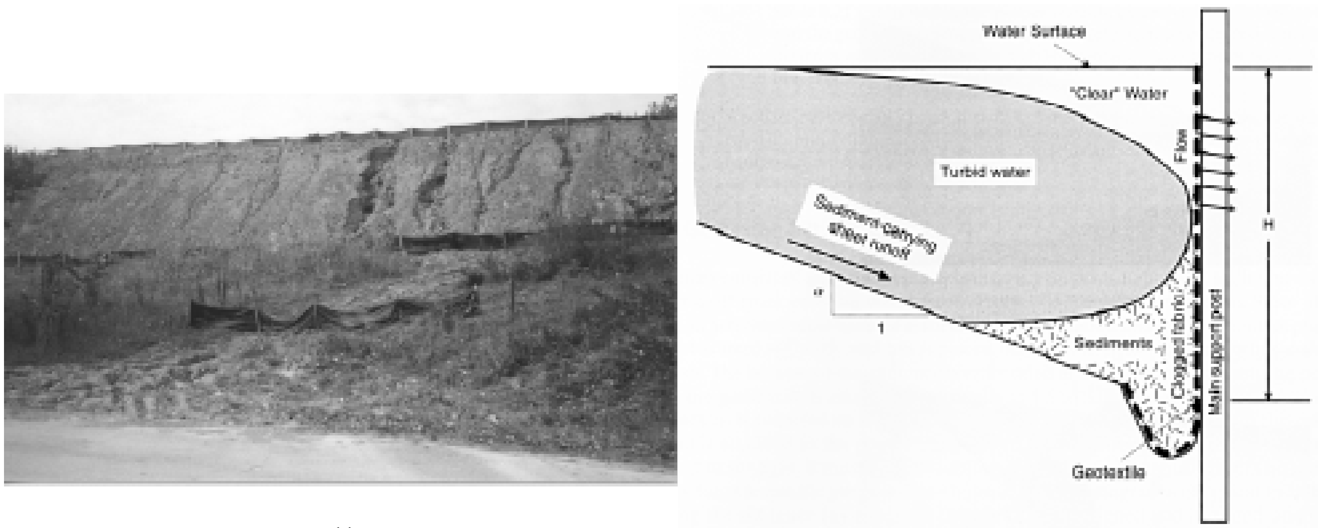


(a) (b)

FIGURE 1. (a) Geotextile silt fence in central Missouri. (b) Schematic of silt fence operation (*3*)

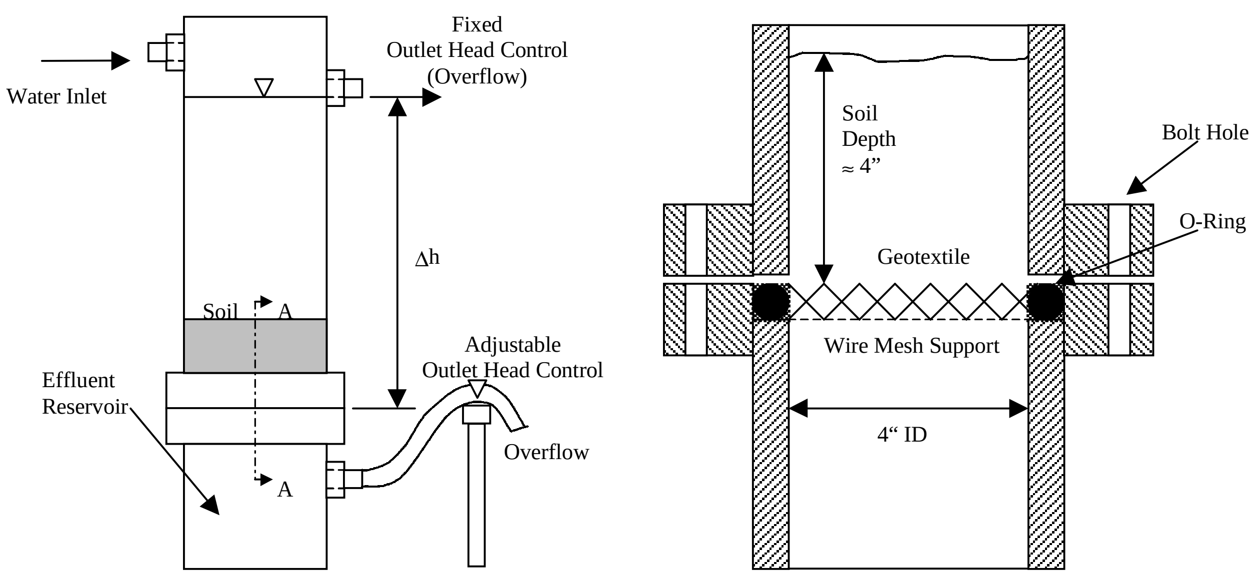


FIGURE 2 Long-term flow test apparatus

hydraulic gradient can be varied by adjusting the elevation of the clear plastic tubing attached to the outlet port of the lower cylinder. The apparatus is back saturated with water from the outlet port of the lower cylinder to 25 mm (1 in.) above the geotextile. The site-specific soil is placed above the geotextile to a depth of 100 mm (4 in.). For loosely placed samples, the soil is placed with a scoop from the top of the upper cylinder in 25 mm (1 in.) to 40 mm (1 ½ in.) layers and leveled with a wooden rod. For compacted samples, the soil is placed in the same manner with each layer receiving 15 blows with a 25 mm (1 in.) diameter by 1 m (3.32 ft) long wooden rod (mass = 438 g) dropped 25 mm (1 in.) per blow. To begin the experiment, the upper cylinder is slowly filled with water from its inlet port until the water reaches the overflow port. Initial flow rates are measured, and the flow is continuous over a long period (up to 2,000 hours in these tests). Flow rate readings are terminated when sufficient definition to the terminal portion (slope m_f) of the flow rate vs. time curve is obtained (Figure 3).

Geotextile Properties

Nine geotextiles supplied for the silt fence market are being tested. The designation and description of the three geotextiles tested to date are provided in Table 1. All geotextiles are a woven polypropylene. Samples 1, 2 and 3 are different-styled silt fences produced by one manufacturer. Tests on materials by other manufacturers are ongoing. To date, twelve tests have been performed.

TABLE 1 Geotextile Properties

GT ID No.	AOS (mm)	Permittivity (sec^{-1})	Permeability (cm/sec)	Water Flow Rate ($L/sec/m^2$)	Manufacturing Process	Composition
1	0.600	0.700	0.025	17	Woven	Polypropylene
2	0.850	0.400	0.007	17	Woven	Polypropylene
3	0.850	0.450	0.014	20	Woven	Polypropylene

*Geotextile properties supplied by manufacturer

TABLE 2 Engineering Properties of Easely Loess Used in this Study

Loess : Sampled from Easley Missouri

Natural moisture content (%)	ASTM D2216	6.0
Specific Gravity	ASTM D854	2.64
Liquid Limit (%)	ASTM D4318	34.6
Plasticity Index	ASTM D4318	14.6
% Passing #200 sieve	ASTM D422	100
% < 0.002 mm (clay fraction, %)		22
Maximum Dry Density (pcf)	ASTM D698	109.0
(Standard Proctor) (kN/m^3)		17.1
Optimum Moisture Content (%)	ASTM D698	16
USCS Group Symbol	ASTM D2487	CL
USCS Group Name		Low Plasticity Clay

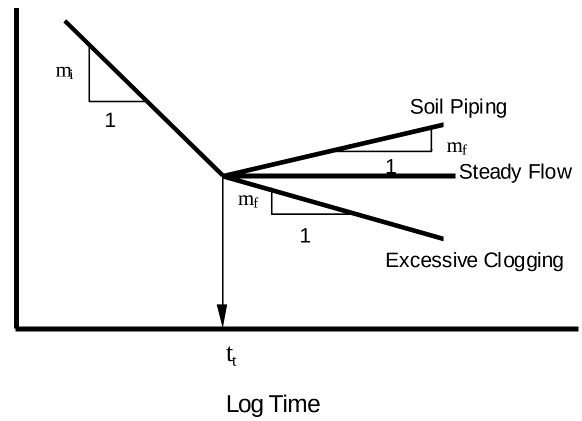


FIGURE 3 Long-term flow rate curves. t_t = time to transition, m_i = initial slope, m_f = final (terminal) slope.

Soil Properties

Mid-Missouri loess is the candidate soil being tested in this study. In Missouri, approximately one-half of the state is covered by loess. The soil has unique characteristics including high stability and strength in its undisturbed, unsaturated state. However, the soil is highly erodable and becomes unstable once it becomes saturated (*5*). The engineering properties of the loess, taken from Easely Missouri, used in this study are shown in Table 2.

The soil was classified as a low plasticity clay (CL) in the USCS. The soil had an average nature moisture content of 6.0 %. All of the particles passed the number 200 sieve (0.074 mm) and the clay size fraction was 22 % by weight. The specific gravity was 2.64. The liquid limit was 34.6 and the plasticity index was 14.6. The maximum dry density, as determined by ASTM D698, was 17.1 kN/m^3 (109.0 pcf) at an optimum moisture content of 16 %.

RESULTS AND DISCUSSION

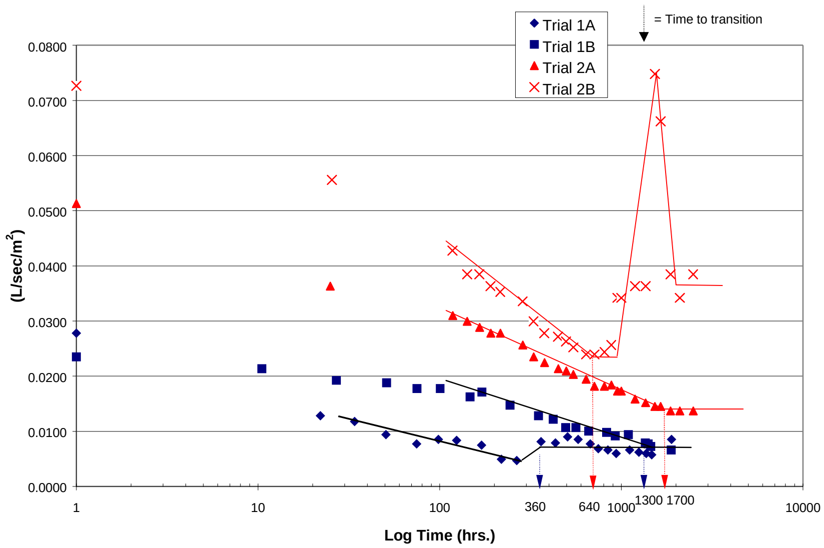
Twelve long-term flow tests have been performed to date using geotextile samples 1, 2 and 3 (Table 3). All soil samples were placed loose except trial 1A, which was compacted to a density of 13.7 kN/m^3 (87.3 pcf). Densities of loosely placed samples ranged from 9.3 kN/m^3 (59.2 pcf) to 11.6 kN/m^3 (73.9 pcf). The moisture content of the soil for trial 1A was 20.0 percent. Remaining trials were tested at moisture content of 11.0 percent.

The results of the long-term flow tests are shown for each geotextile in Figure 4. Initial flow rates ranged from 0.016 to 0.073 $L/sec/m^2$ ($1 L/sec/m^2 = 0.024\ gal/sec/ft^2$). This is about 4 orders of magnitude lower then the flow rates reported for the geotextiles alone (Table 1). Obviously, the loess dominates the flow rate, as we would expect. It is interesting to note that these flow rates are one to two orders of magnitude lower than those for mica silt as reported by Koerner 1998. Loess is a much finer-grained soil, and the lower flow rate is expected.

In all cases, the flow rates immediately begin to decrease with continuous flow of water through the soil-geotextile systems (Figure 4). The initial decrease (slope m_i, as defined in Figure 3) is due to densification of the soil from the effects of seepage forces. After a given time of flow, referred to as transition time (t_t), the slope of the flow rate versus log time plot changes. At this point, it is assumed that all soil densification has taken place and changes in flow rate are primarily a function of the soil-geotextile compatibility, i.e., if the geotextile is clogging, flow rates continue to decrease, or if the flow rate is increasing, fines are piping through the geotextile. Both cases would be of concern for long-term performance of the geotextile with that particular soil.

In the cases tested, the transition times ranged from 360 to 2,000 hours (Table 3, Figure 4). Typical transition times are around 10 hours for granular soils and 200 hours for fine-grained soils (*3*). The longer transition times measured herein are thought to result from the nature of the loess – all particles less than 0.074 mm and very low cohesion. The larger the fine fraction and the lower the cohesion, the longer the time to transition.

After the time to transition, all of the geotextile-soil combinations showed a relatively steady flow rate. This finding indicates that the loess did not tend to clog or pipe through the geotextiles. From this perspective, the loess and the geotextiles tested are compatible. No measurable fines were collected from the effluent water. It must also be noted that the final, steady flow rates through the geotextile-loess systems were low and dramatically decreased from the initial flow rates. In all but one case, the flow rates decreased (from initial values) by more than 50% (Table 3). While the final flow rates were steady, the low magnitude could result in excessive ponding in the case of silt fence applications or in excessive porewater pressure buildup in the case of filtration applications.



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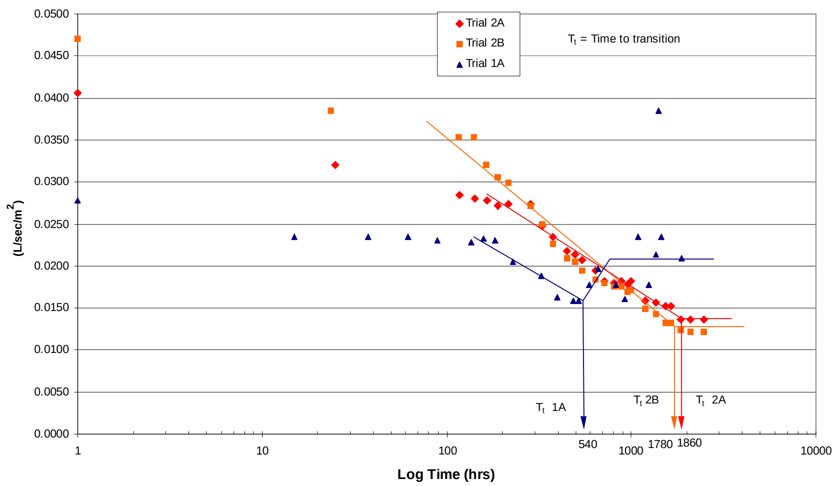

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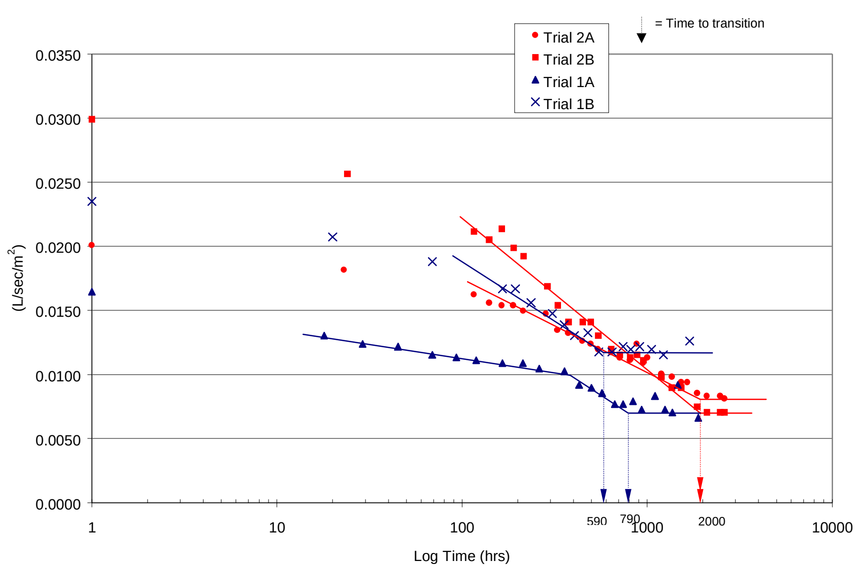

(c)

FIGURE 4 Results for geotextile silt fence material and Easely loess

TABLE 3 Long Term Flow Results for Geotextile/Loess Systems

GT ID No.	Trial	Placement Method	Placed Density (kN/m^3)	Moisture Content (%)	Initial Flow Rate (L/sec/m^2)	Time To Transition (hrs)	Final Flow Rate (L/sec/m^2)	Percent Decrease Flow Rate
1	1A	Compacted	13.7	20.0	0.029	360	0.008	73
1	1B	Loose	10.4	11.0	0.026	1300	0.008	70
1	2A	Loose	11.4	11.0	0.051	1700	0.014	73
1	2B	Loose	10.7	11.0	0.073	640	0.025	66
2	1A	Loose	10.7	11.0	0.028	540	0.021	25
2	2A	Loose	11.2	11.0	0.047	1860	0.014	71
2	2B	Loose	11.0	11.0	0.041	1780	0.012	71
3	1A	Loose	9.3	11.0	0.016	790	0.007	56
3	1B	Loose	10.7	11.0	0.024	590	0.013	46
3	2A	Loose	11.6	11.0	0.020	2000	0.008	60
3	2B	Loose	11.2	11.0	0.030	2000	0.007	77

LESSONS LEARNED

Long-term flow tests have been completed on three of nine candidate geotextiles with loess. Several insights have been gained and lessons learned from the test results that extend to field applications and future considerations of geotextile applications in loess.

Test Results

- Transition times, t_t, for geotextile-loess can be excessive (up to 2,000 hours).
- Final flow rates through the geotextile-loess system can be more than 50% less than the initial flow rate.
- No excessive fines passed through the geotextile.

Implications for the Field

- The tested geotextiles should perform well for silt fence in loess application.
- Geotextiles in filtration applications in loess may provide insufficient flow rates and could result in build up of excessive porewater pressures.
- Designers should evaluate required flow rates to assure excess porewater pressures do not build up, especially in filtration applications in loess.

Further Considerations

- Long transition times make routine laboratory testing prohibitive. It appears that as the percent fines increase, the time to transition increases. The effect of percent fines on time to transition should be evaluated. Designers could then predict time to transition simply based on the grain size distribution for a soil.
- The long-term flow test results are directly applicable to the field performance of geotextiles in filtration applications, i.e., wrapping aggregate in a “French Drain” application. However, the performance of geotextiles used as silt fence in loess should be evaluated using a specifically designed performance test for silt fences, such as ASTM D5141, “Determining Filtration Efficiency and Flow Rate of a Geotextile Silt Fence Application, Using Site Specific Soil”.

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